PRODUCT DATA

Sound Intensity Probe Kit for 2260 — Type 3595
Sound Intensity Microphone Pair — Type 4197
Dual Preamplifier — Type 2683

Type 3595 is a two-microphone probe kit for measuring sound intensity. Specially designed for use with 2260 Investigator™ Hand-held Sound Intensity System, the probe set includes the $^{1}/_{2}$″ Sound Intensity Microphone Pair Type 4197 enabling $^{1}/_{3}$-octave centre frequency measurements between 20 Hz and 6.3 kHz. Extending the upper $^{1}/_{3}$-octave centre frequency to 10 kHz can be achieved using pressure correction.

Used with $^{1}/_{2}$″ Microphone pair Type 4197, the probe complies with IEC 1043 Class 1. These $^{1}/_{2}$″ microphones feature patented phase-corrector units making precision low-frequency phase matching a practical possibility, leading to increased measurement range and accuracy.

3595

Brüel & Kjær

Uses and Features

USES

- ❍ Sound intensity measurements using two-microphone technique, in accordance with IEC 1043 Class 1
- ❍ Sound power measurements in accordance with ISO 9614–1, ISO 9614–2, ECMA 160 and ANSI S 12–12

FEATURES

- ❍ Microphone pair matched for phase and amplitude response
- ❍ Individual calibration data
- ❍ $^{1}/_{3}$-octave centre frequency ranges:
  20 Hz to 10 kHz with corrections
  50 Hz to 6.3 kHz according to IEC 1043 Class I
- ❍ Minimal shadow and diffraction effects
- ❍ Well-defined acoustical microphone separation
- ❍ Specially designed for use with Hand-held Sound Intensity System Type 2260E

Introduction

Fig. 1 The Hand-held Sound Intensity System consisting of 2260 Investigator™ and Sound Intensity Software BZ 7205 and Sound Intensity Probe Kit Type 3595 is supplied in a carrying case

The measurement of sound intensity (sound power per unit area) is increasingly being used as a routine technique in a wide range of noise investigations. The method permits the determination of sound power from direct measurement of sound intensity, even in situations where pressure-based measurements would be impossible. Since the method does not require special acoustic environments such as reverberation and anechoic chambers, significant savings can also be made

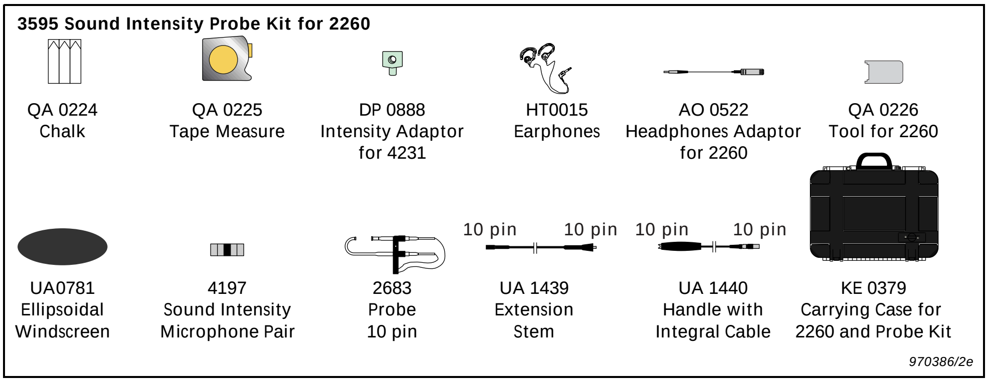
To measure sound intensity accurately using a two-microphone technique, you need a reliable sound intensity probe set containing a matched microphone pair to obtain information on both the instantaneous pressure and pressure gradient in the sound field. The microphones are separated by a fixed distance in the sound field, and the microphone signals are fed to a sound intensity processor which calculates the sound intensity. The sound intensity is calculated from the time average of the sound pressure multiplied by the particle velocity (calculated from the measured pressure gradient). Such a system measures the component of the sound intensity along the probe axis and also indicates the direction of energy flow.

Fig. 2 The sound intensity probe consists of: Dual Preamplifier Type 2683 and Sound Intensity Mirophone Pair Type 4197. Here you can see it placed on an extension stem

Note: Microphone Pair Type 4197 is a direct replacement for the earlier Microphone Pair Type 4181. The improvements in the Type 4197 include new stainless steel alloy diaphragm, a new robust grid, new calibration chart, and a slightly greater sensitivity. Otherwise the specifications of the 4197 and 4181 are virtually the same

Several sound intensity probe sets are available from Brüel & Kjær: Types 3583 and 3584 are for use with Brüel & Kjær analyzers e.g., Types 2144, 2133 and PULSE™ 3560 (see separate Product Data Sheet for Types 3583/3584). Sound Intensity Probe Set 3595 is intended for use with 2260 Investigator. (Fig. 1). The Dual Preamplifier Type 2683 with Microphone Pair Type 4197, Extension Stem UA 1439 and Handle with Integral Cable UA 1440 can also be used with other intensity systems, e.g., NEXUS™ Conditioning Amplifier Type 2691. The characteristics of the Sound Intensity Probe Kit Type 3595 and Sound Intensity Microphone Pair 4197 are described in this Product Data sheet.

Fig. 3 The sound intensity probe kit



For further details of the sound intensity analyzers and information on which probe set is suitable for which analyzer, see the separate Product Data sheets for the analyzers.

Probe Description

The sound intensity probe is constructed on a face-to-face design. It consists of a robust frame which holds the microphone preamplifier(s) and matched microphones in a face-to-face configuration. The distance between the microphones is defined by solid plastic spacers which are held in place by threaded studs on the microphone grids. Sound is constrained to act on each microphone through a narrow slit between the spacer and the microphone grid. This arrangement gives well-defined acoustic separation of the microphones and minimises shadow and reflection effects.

The probe is strong but lightweight and can be held using either a handle with integral cable ending in a 10 pin LEMO plug or with an extension rod. The probe can be connected to 2260 Investigator via a cable or an extension rod. All the probe sets are supplied in transport cases containing a microphone pair, windscreen (ellipsoidal) and accessories.

The case has pockets to accomodate 2260 Investigator, a Sound Level Calibrator Type 4231 and other small accessories.

Type 3595 is supplied with $^{1}/_{2}$″ Sound Intensity Microphone Pair Type 4197. These microphones operate on a polarization voltage of 200 V.

Sound Intensity Microphone Pairs

Phase matching of the $^{1}/_{2}$″ microphone pair Type 4197 is better than 0.05° between 20 Hz and 250 Hz, and is better than $^{f}/_{5000}$ degrees at higher frequencies, where f is the frequency. Such phase matching is possible as a result of the integral microphone phase-corrector units (patented) which are fitted to the 4197 microphones. The normalised microphone frequency responses differ by less than 0.2 dB up to 1 kHz and by less than 0.4 dB up to 7.1 kHz.

Type 4197 is supplied with 8.5 mm, 12 mm and 50 mm spacers. Calibration data provided (Fig. 4) include phase matching up to a $^{1}/_{3}$-octave centre frequency of 6.3 kHz, microphone sensitivities at 250 Hz, actuator responses and individual free-field frequency responses valid for the microphones mounted on a $^{1}/_{4}$″ preamplifier.

Fig. 4 Calibration chart supplied with the 4197 microphone pair. The measured microphone phase matching and individual microphone free-field responses are given

Sound Intensity Microphone Pair
Type 4197
Calibration Chart

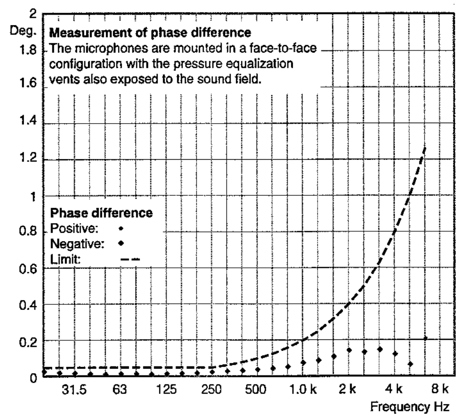
Brüel & Kjær

Serial No: 2113360	Part 1	Part 2	
Open-circuit Sensitivity, S_0:	*-38.5*	*-38.4*	dB re 1V/Pa
Equivalent to:	*11.9*	*12.0*	mV/Pa
Uncertainty, 95 % confidence level		0.2	dB
Capacitance:	*19.4*	*19.4*	pF
Vent Sensitivity, 20 Hz: (re diaphragm sens.):	*-76.7*	*-76.4*	dB
Valid At:			
Temperature:		23	°C
Ambient Static Pressure:		101.3	kPa
Relative Humidity:		50	%
Frequency:		251.2	Hz
Polarization Voltage, external:		200	V

Sensitivity Traceable To:
DPLA: Danish Primary Laboratory of Acoustics
NIST: National Institute of Standards and Technology, USA

Environmental Calibration Conditions:
100.0 kPa 24 °C 36 % RH

Procedure: 704619 **Date:** 6. Apr. 1998 **Signature:**



Frequency Response (re 250Hz) :

1/3 Octave Centre Frequency [Hz]	Part 1 Actuator Response [dB]	Part 1 Free Field Response 0° Sound Incidence [dB]	Part 2 Actuator Response [dB]	Part 2 Free Field Response 0° Sound Incidence [dB]
250	-0.00	-0.00	-0.00	-0.00
-	-	-	-	-
1000	-0.08	0.01	-0.09	0.01
1250	-0.12	0.02	-0.13	0.02
1600	-0.18	0.03	-0.19	0.02
2000	-0.27	0.04	-0.28	0.03
2500	-0.41	0.04	-0.43	0.03
3150	-0.63	0.05	-0.65	0.03
4000	-0.95	0.08	-0.97	0.06
5000	-1.41	0.13	-1.45	0.10
6300	-2.17	0.11	-2.19	0.08
8000	-3.12	0.21	-3.18	0.15
10k	-4.48	0.32	-4.54	0.26

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Brüel & Kjær also supplies a $^1/_4''$ Microphone Pair Type 4178 which consists of a pair of $^1/_4''$ microphones, phase matched to better than 0.2° from 20 Hz to 1 kHz and sensitivity matched to better than 1 dB.
Type 4178 is supplied with 6 mm and 12 mm spacers, along with calibration charts giving the individually measured free-field frequency response for each microphone.

IEC 1043 Standard

The IEC 1043 standard (Electroacoustics – Instruments for the measurement of intensity – measurement with pairs of pressure sensing microphones, 1993) distinguishes between Probe, Processor and Instrument and classifies them according to the measurement accuracy achieved. There are two degrees of accuracy, Class 1 and Class 2. The Brüel & Kjær probe set complies with IEC 1043 Class 1 which has the most stringent tolerance requirements. Note, however, that the IEC standard only specifies the frequency range from centre frequencies of 50 Hz to 6.3 kHz in $^1/_3$-octave bands.

Frequency Range

The useful free-field frequency range according to IEC 1043 Class I for Type 3595 using the various microphone and spacer combinations, is from $^1/_3$-octave centre frequencies of 50 Hz to 6.3 kHz. However, using the actuator response correction described in an article by Prof. F. Jacobsen in Brüel & Kjær's Technical Review Nr. 1, 1996 (BV 0048), the frequency response can be extended to 10 kHz using just the 12 mm spacer. The actual frequency range in practice depends on the difference between the pressure and intensity levels, i.e., Pressure-Intensity Index, which is dependent on the nature of the sound field and the phase response deviation between the probe and processor channels.

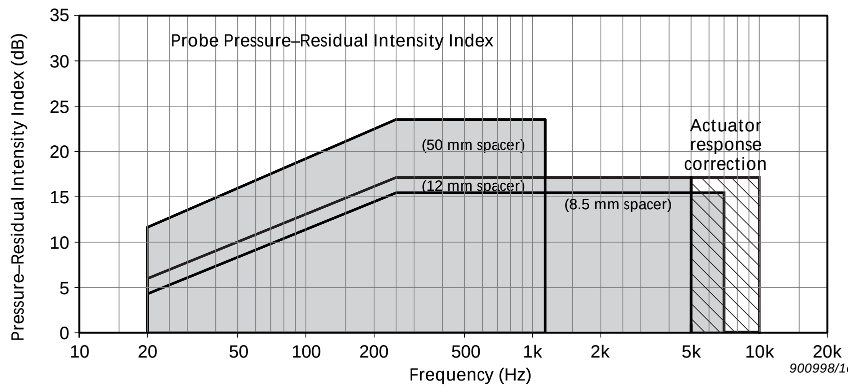


Fig. 5 Specified frequency and Pressure-Residual Intensity Index ranges for the probe (Pressure-Residual Intensity Index = Pressure Level – Intensity Level (measured in a closed coupler)). Frequency axis is in $^1/_3$-octave centre frequencies

The overall frequency ranges are shown in Fig. 5 for $^1/_2$″ Microphone Pair Type 4197 with 8.5, 12 and 50 mm spacers. Note that the frequency range depends on the difference between the pressure level and the intensity level. In most field measurements, the sound intensity level is lower than the sound pressure level. The ability of a sound intensity instrument to measure intensity levels much lower than the pressure level depends on the probe and processor phase matching. The difference between pressure and intensity levels is called the *Pressure-Intensity Index* which is denoted by δ_{pI} and is normally a positive quantity.

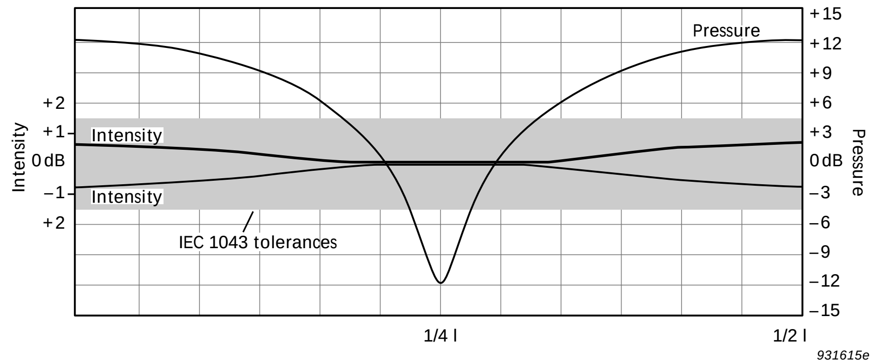
δ_{pI_0} is the Pressure-Residual Intensity Index of the measurement instrumentation (shown for the probe by the limits of the shaded area in Fig. 5). δ_{pI_0} is determined by the phase (mis)match of the system, and its effect on the accuracy of a measured sound intensity level is determined by the value chosen for the constant K. If K is 7 dB, then an accuracy of ±1 dB can be expected. If K is 10 dB then the accuracy will be ±0.5 dB (the sign of this bias error depends on the sign of the system's phase mismatch). Measurements must be restricted to values of δ_{pI} given by:

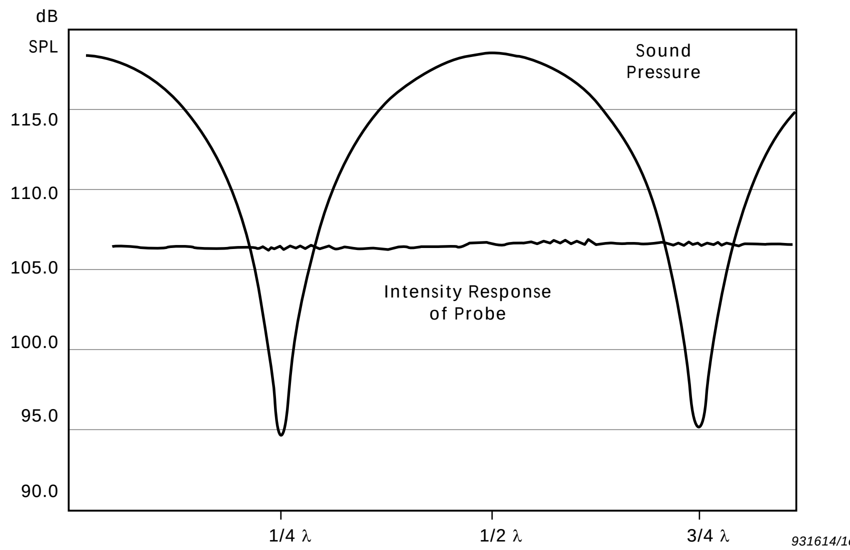
$$\delta_{pI} \leq \delta_{pI_0} - K$$

The Pressure-Residual Intensity Indices for the intensity probe set, shown in Fig. 5 (solid lines), are derived directly from the phase matching specifications.

As the static pressure equalization vent may cause problems, the IEC 1043 standard specifies that probes designed to operate at frequencies below 400 Hz must be tested in a plane standing wave field. The standing wave ratio must be 24 dB at a frequency between 125 and 400 Hz. Fig. 6 illustrates the performance of the Brüel & Kjær intensity probe for this test at 125 Hz.

Fig. 6 The upper graph illustrates the calculated intensity response limits relative to a standing wave, for a probe consisting of Sound Intensity Microphone Pair Type 4197 and Dual Preamplifier Type 2683. The calculation is valid for the maximum phase deviation specified for the microphone pair and preamplifier configuration and for field conditions according to IEC 1043 (50 mm spacer at 125 Hz and a standing wave ratio of 24 dB). In practice the intensity response of the probe is significantly better as shown in the typical measurement in the lower graph

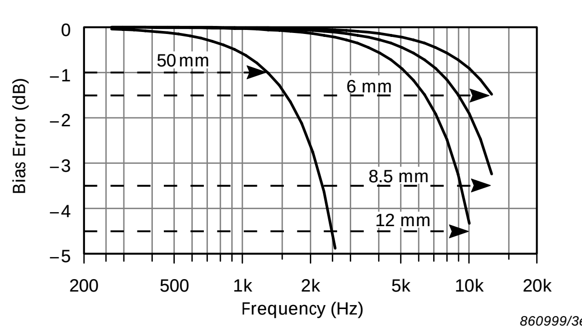




High-Frequency Limit

The upper limit of the frequency range for a sound intensity probe set depends on the length of the microphone spacer. Approximating the pressure gradient using two microphones separated by a short distance in the sound field leads to an underestimate of the sound intensity level, but the error is less than 1 dB as long as the distance between the microphones is less than one sixth of the wavelength. This means that for high-frequency measurements, a short spacer should be used. The bias error is plotted as a function of frequency for the different microphone spacers in Fig. 7. To keep this error to less than 1 dB, the appropriate spacer is chosen for the frequency range of interest. 50 mm, 12 mm and 8.5 mm spacers are used with $^1/_2$″ microphones up to $^1/_3$-octave centre frequencies of 1.25 kHz, 5 kHz and 6.3 kHz respectively; 12 mm and 6 mm spacers with $^1/_4$″ microphones up to $^1/_3$-octave centre frequencies of 5 kHz and 10 kHz respectively.

Fig. 7 High-frequency bias error in sound intensity measurements (for plane waves, 0° incidence). The upper frequency limits (–1 dB error) for the different spacers are indicated

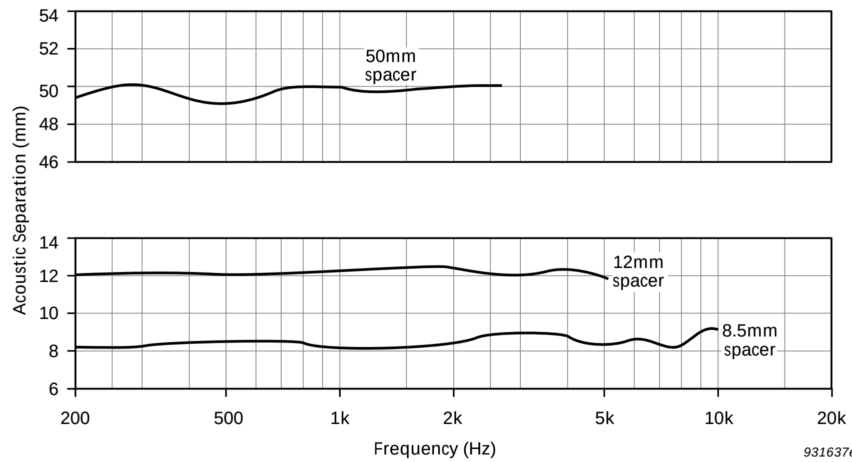


Extension of frequency range to 10 kHz using $^1/_2$″ microphones and 12 mm spacer is described in Brüel & Kjær Technical Review No.1 1996 and Product Data sheet for 2260.

Effective acoustical separation of probe microphones

It is important that a sound intensity probe does not disturb the sound field it is measuring. The face-to-face configuration and the optimised mechanical design of the Brüel & Kjær probe means that the disturbance of the sound field is very small.

Fig. 8 Measurement of the variation of effective acoustical separation as a function of frequency for 4197 microphones with 50 mm, 12 mm and 8.5 mm spacers



The spacers used to separate the microphone pairs in the sound field are designed to give acoustic separations of 6 mm, 8.5 mm, 12 mm and 50 mm. Their physical lengths in fact differ slightly from these values. The effective acoustical separation of the microphones varies slightly as a function of frequency due to reflections. This effect is minimised by the solid spacers which separate the microphones, and the distance variation is less than 0.5 mm for the 12 mm spacer as shown in Fig. 8. The effect on the accuracy of the measured sound intensity is consequently very small.

Fig. 9 Comparison measurement of sound intensity measured using Microphone Pair Type 4197 with the actual sound intensity

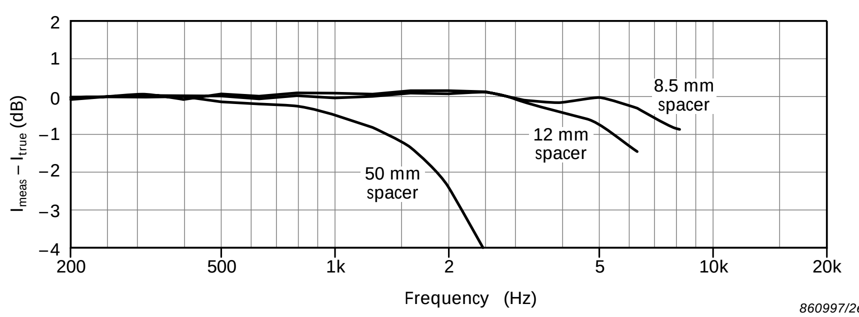
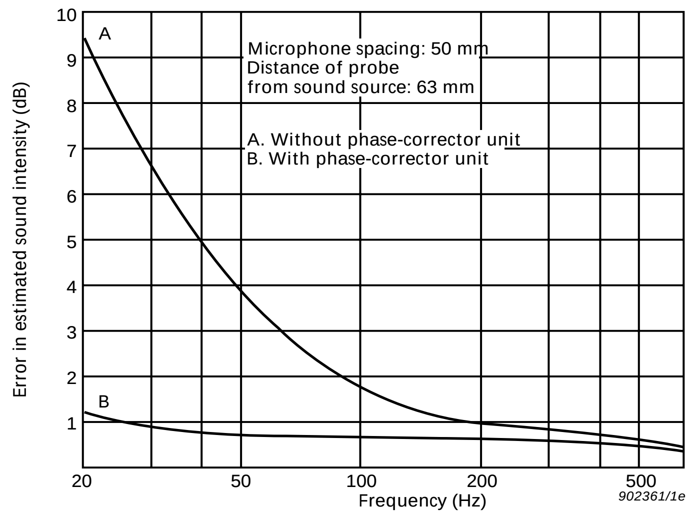


Fig. 9 shows the difference between the true intensity and the measured intensity in a free field. The typical response shown in this graph includes all the possible sources of error: phase mismatch, free-field corrections, microphone distance variation and the high-frequency approximation error (the latter giving a –1 dB error at centre frequencies of 1.25 kHz, 5 kHz and 6.3 kHz respectively).

Patented microphone phase-corrector units

The phase matching specified for the 4197 microphone pair is retained even in sound fields with very high pressure-level gradients, such as those found close to point sources. This is a benefit of the patented phase-corrector units which are fitted to these microphones. Ordinary condenser microphones can have their phase responses altered if there is a difference between the pressure level at the pressure equalisation vent and that at the diaphragm. Type 4197 microphones are, however, essentially insensitive to sound at the vent and the accuracy of near-field measurements at low frequencies is consequently increased (Fig. 10).

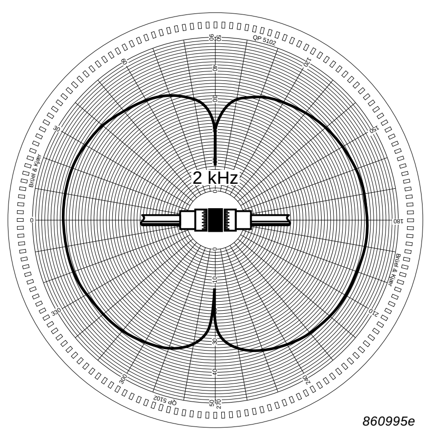
Fig. 10 The phase-corrector units fitted to the 4197 suppress vent sensitivity and result in more accurate near-field measurements



Directional Characteristics

Typical directional characteristics for a sound intensity probe are given in Fig. 11, which shows the measured intensity as a function of angle of incidence. This figure-of-eight characteristic is due to the fact that a sound intensity system measures the component of the sound intensity along the probe axis, i.e. $I_{meas} = I\cos\theta$. The minimum feature of the probe's characteristics can be used to help locate sound sources.

Fig. 11 Measured directional intensity-characteristics for a probe set fitted with 4197 microphones and a 12 mm spacer at 2 kHz



Calibration

Phase calibration of the $^1/_2$″ Microphone Pair Type 4197 is done at Brüel & Kjær by subjecting the two microphones to the same sound signal in a pressure coupler. This individual phase calibration can be used to derive the actual Pressure-Residual Intensity Index for the microphone pair. If only amplitude (pressure) calibration is required, the two channels can be calibrated separately using a Pistonphone Type 4228 or together using Sound Level Calibrator Type 4231 with Coupler DP 0888.

Fig. 12 Complete calibration of sound intensity measurement systems containing a sound intensity probe set can be conveniently made using a Sound Intensity Calibrator Type 3541. This permits simultaneous sensitivity adjustment of both channels of the processor (in both pressure, particle velocity or intensity modes) and allows determination of the Pressure-Residual Intensity Index of the probe and processor combinations which employ microphone pairs with phase-corrector units, i.e., Type 4197. Further details can be found in the separate Product Data for Type 3541

Fig. 13 Sound Intensity Calibrator Type 4297 with a Sound Intensity Probe in place for calibration. The advantage of this calibrator is that the probe need not be dismantled to perform a calibration. Further details can be found in the separate Product Data for Type 4297

Specifications for Sound Intensity Probe Kit 3595

Matched Sound Intensity Microphone Pairs:

Sound intensity free-field frequency ranges (centre frequency – 1/3-octave) with 1/2" microphones Type 4197 connected to Dual Preamplifier Type 2683 (IEC 1043 Class 1):
8.5 mm spacer: 250 Hz to 6.3 kHz (δ_{pI_0} > 15.3 dB)[1]
12 mm spacer: 250 Hz to 5.0 kHz (δ_{pI_0} > 16.8 dB)
50 mm spacer: 20 Hz to 1.25 kHz (δ_{pI_0} > 23 dB above 250 Hz)

1.Pressure-Residual Intensity Index

Sound intensity free-field frequency ranges with 1/4" microphones Type 4178 (optional accessory, see Product Data sheet for 3583, 3584):
6 mm spacer: max. 10.0 kHz
12 mm spacer: max. 5.0 kHz

Dimensions:
Length of Extension Stem: 42 cm (16.5 in)
Width: 43 mm (1.7 in)

Weight:
Incl. handle: 0.35 kg (0.77 lb)
In case: 6.50 kg (14.3 lb)

Specifications Sound Intensity Microphone Pair 4197

Type		4197
Diameter		1/2"
Polarization voltage (V)		200
Open-circuit sensitivity	mv/Pa	11.2*
	dB re 1 V/Pa	–39
Free-field frequency response 0° incidence	±1 dB	5 Hz to 12.5 kHz*
	±2 dB	0.3 Hz to 20 kHz
Resonance frequency		34 kHz
Lower limiting frequency	–3 dB	0.14 Hz
Vent sensitivity re diaphragm sensitivity	at 20 Hz	<–64 dB* (–18 dB/octave)
Polarized cartridge capacitance	at 250 Hz	19.5 pF*
Cartridge thermal noise		20.0 dB(A)
Upper limit of dynamic range	Distribution <3%, 100 Hz	162 dB SPL
Temperature coefficient	–10°C to +50°C, 250 Hz	–0.002 dB/°C
Ambient pressure coefficient	at 250 Hz	–0.0007 dB/hPa
Humidity coefficient	100% RH	<0.1 dB
Vibration sensitivity	at 1 m/s²	65.5 dB SPL
Magnetic field sensitivity	50 Hz, 80 A/m	6 to 34 dB SPL
Thread for preamplifier mounting		5.7 — 60 UNS
Accessories included		8.5 mm spacer UC 5349 12 mm spacer UC 5269 50 mm spacer UC 5270

*Individually calibrated

Microphone Matching Specifications		
Type		4197
Phase response difference (absolute value) (1/3-octave centre frequencies)		<0.05°: 20 Hz to 250 Hz* $< \frac{f[\mathrm{Hz}]^\circ}{5000}$: 250 Hz to 6.3 kHz*
Amplitude response difference	normalized at 200 Hz	<0.2 dB: 20 Hz to 1 kHz <0.4 dB: 20 Hz to 7.1 kHz
Sensitivity difference	at 250 Hz	<1 dB
Polarized capacity difference		<1.0 pF

Specifications Dual Preamplifier 2683

Phase matching		<0.015° at 50 Hz (20 pF mic. capacitance) f [kHz]×0.06°: 250 Hz to 10 kHz
Electrical noise re microphone sensitivity‡	$^1/_4$″ 6.4 pF dummy	39.2 dB SPL (A)
	$^1/_2$″ 19.5 pF dummy	19.4 dB SPL (A)
Input impedance		>15 GΩ‖XX pF where XX is typically for Ch. A = 1.1 pF; for Ch. B = 0.4 pF
Attenuation	For $^1/_2$″ microphones	Ch. A = 0.6 dB; Ch. B = 0.3 dB
	For $^1/_4$″ microphones	Ch. A = 1.7 dB; Ch. B = 0.7 dB
Other specifications		Refer to Product Data (BP 1584) for Type 2670

‡This corresponds to a total (Microphone + Preamplifier) noise floor of 39.3 dB SPL (A) and 22.7 dB SPL (A) respectively.
Note: All values are typical at 25°C (77°F), unless measurement uncertainty is specified. All uncertainty values are specified at 2σ (i.e., expanded uncertainty using a coverage factor of 2)

Compliance with Standards

CE	CE-mark indicates compliance with: EMC Directive and Low Voltage Directive.
Safety	EN 61010–1 and IEC 1010–1: Safety requirements for electrical equipment for measurement, control and laboratory use.
EMC Emission	EN 50081–1: Generic emission standard. Part 1: Residential, commercial and light industry. EN 50081–2: Generic emission standard. Part 2: Industrial environment. CISPR 22: Radio disturbance characteristics of information technology equipment. Class B Limits. FCC Rules, Part 15: Complies with the limits for a Class B digital device.
EMC Immunity	EN 50082–1: Generic immunity standard. Part 1: Residential, commercial and light industry. EN 50082–2: Generic immunity standard. Part 2: Industrial environment. **Note:** The above is guaranteed using accessories listed in this Product Data sheet only.
Temperature	IEC 68–2–1 & IEC 68–2–2: Environmental Testing. Cold and Dry Heat. Operating Temperature: –10 to +50°C (+14 to +122°F) Storage Temperature: –25 to +70°C (–13 to +158°F)
Humidity	IEC 68–2–3: Damp Heat: 90% RH (non-condensing at 40°C,104°F)

Ordering Information

Accessories included (Type 3595):

Type 4197: Microphone Pair including spacers:
UC 5349: 8.5 mm spacer
UC 5269: 12 mm spacer
UC 5270: 50 mm spacer
Type 2683: Dual Preamplifier
UA 1439: Extension Stem
UA 1440: Handle with Integral Cable
UA 0781: Ellipsoidal Windscreen
DP 0888: Coupler
HT 0015: Earphones
AO 0522: Adaptor Lemo to Jackplug
QA 0224: Chalk
QA 0225: Tape Measure
QA 0226: Tool for 2260
KE 0379: Carrying Case

Optional Accessories

CALIBRATION EQUIPMENT:

Type 4228: Pistonphone
Type 4231: Sound Level Calibrator
Type 3541: Sound Intensity Calibrator (includes Type 4228)
Type 4297: Sound Intensity Calibrator

MICROPHONES:
Type 4178: $^1/_4$″ Sound Intensity Microphone Pair (with 6 and 12 mm spacers)

SPACERS:
For $^1/_4$" Microphones Type 4178
UC 0196: 6 mm spacer
UC 0195: 12 mm spacer

EXTENSION CABLES:
AO 0441: 3 m Single Cable Extension (10 pin LEMO)
AO 0442: 10 m Single Cable Extension (10 pin LEMO)
JP 1040: Branched plug 10 pin LEMO to two 7-pin LEMO

BP 1796–12 01/11 Rosendahls Bogtrykkeri

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